How to design masonry structures using Eurocode 6

3. Lateral resistance

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Introduction

The introduction of European standards to UK construction is a significant event. The ten design standards, known as the Eurocodes, will affect all design and construction activities as current British standards for design are due to be withdrawn in March 2010.

This publication is part of a series of three guides entitled *How to design masonry structures using Eurocode 6*. The aim is to make the transition to Eurocode 6, *Design of masonry structures* as easy as possible by drawing together in one place key information and commentary required for the design of typical masonry elements.

The Concrete Centre and the Modern Masonry Alliance recognised that effective guidance is required to ensure that the UK design profession is able to use Eurocode 6 quickly, effectively, efficiently and with confidence. Therefore a steering group, with members from across the masonry industry (see back cover for a list of members), was established to oversee the development of these guides.

Guidance for lateral resistance

This guide is the third in a series of three giving guidance on the design of masonry structures to Eurocode 6[1]. The first guide, *Introduction to Eurocode 6*[2] gives an introduction to design and assessment of actions using Eurocode 6 and also covers the specification and workmanship of masonry. The second guide in the series[3] covers the design of vertically loaded masonry. This guide explains how to design for horizontal actions. Throughout this guide the Nationally Determined Parameters (NDPs) from the UK National Annexes (NAs) have been used. These enable Eurocode 6 to be applied in the UK.

Eurocode 6 methods for lateral resistance

Eurocode 6 offers two approaches to the design of laterally loaded panels. The first method relies on the flexural strength of the masonry and makes use of yield line analysis to provide bending moment coefficients. The second method is an approach based on arching and the assumption of a three-pinned arch being formed within the wall. Both methods are presented in this guide.

The flexural strength approach is the most widely used and does not depend upon rigid supports to resist arch thrust. In the UK, the reliance on the development of tensile strength in the masonry has meant that this design approach has usually been limited to transitory loads only. Eurocode 6 indicates that the flexural strength of masonry should not be used in the design of walls subjected to permanent lateral actions, e.g. gravity or reinforced walls.

The assessment of the edge conditions is a requirement for the flexural strength approach. A free edge is easily identified but some judgement on the part of the engineer is necessary in deciding between simply supported or fixed conditions. When considering the vertical support condition, attention also needs to be paid to the potential position of movement joints and the changes the provision of such joints make to the panel size and restraint conditions.

Where the walls are not rectangular, for instance a trapezoidal-shaped wall to a mono-pitched structure, engineering judgement may be applied to determine the effective wall height.

Wall panels with openings need to be treated with care and may typically be sub-divided into smaller panels around the opening. It is beyond the scope of this guide to deal with the topic in detail and reference should be made to suitable handbooks[4,5]. Alternatively, a yield line analysis from first principles may be used; the guidance in *Practical yield line design*[6] can be applied to wall panels.

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If a damp proof course (dpc) is present in a wall subjected to flexure then the degree of fixity may be altered. The bending moment coefficient at a dpc may be taken as that for an edge over which full continuity exists, provided that there is sufficient vertical load on the dpc to ensure that the flexural strength capacity is not exceeded.

Walls may be either horizontally and/or vertically spanning and the ultimate strength of the wall is governed by the capacity of the masonry to resist flexural tension. This capacity is enhanced by the presence of vertical load. Clearly the potential flexural strength is greater if the potential plane of failure is perpendicular rather than parallel to the bed joint.

Figure 1 shows a flow chart for lateral load design. The designer needs to assess the panel support conditions (or assume a free edge) and decide whether these provide simple or continuous (fully restrained) support. Care also needs to be exercised in considering the effect of dpcs, movement joints, openings in walls, etc. There are handbooks that provide further guidance on these aspects[4,5].

Bending moments using coefficients

For panels without openings, the bending moments per unit length (M_{Ed}) are:

$M_{Ed1} = \alpha_1 W_{Ed} l^2$ when the plane of failure is parallel to the bed joints

$M_{Ed2} = \alpha_2 W_{Ed} l^2$ when the plane of failure is perpendicular to the bed joints

where

α_1 = bending moment coefficient parallel to the bed joints ($= \mu\alpha_2$, see Table 2)

α_2 = bending moment coefficient perpendicular to the bed joints (see Table 2)

W_{Ed} = design wind load per unit area ($\gamma_Q W_K$)

l = length of panel between supports

μ = orthogonal ratio (f_{xk1}/f_{xk2})

Lateral resistance using flexural strength

The presence of a vertical load increases the flexural strength of a panel in the direction parallel to the bed joints. The design moment of resistance within the height of the wall is given by:

$$M_{Rd} = \left(\frac{f_{xk1}}{\gamma_M} + \sigma_d\right) Z$$

where

f_{xk1} = characteristic flexural strength of masonry bending about an axis parallel to bed joints (see Table 1)

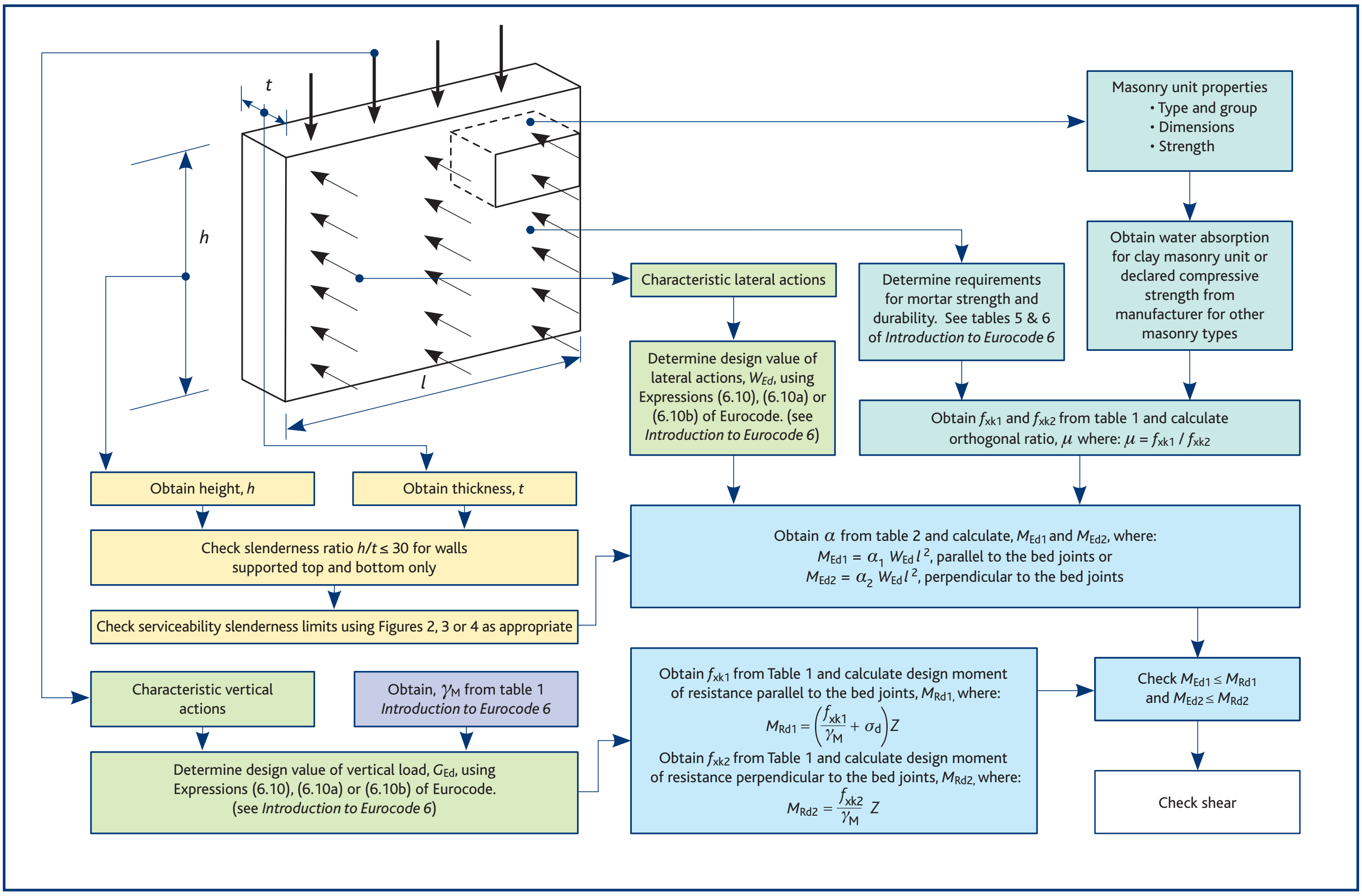
γ_M = appropriate partial factor for materials

σ_d = design vertical load per unit area ($< 0.2\, f_k/\gamma_M$)

Z = section modulus of the plan shape of the wall

f_k = characteristic compressive strength (see *Vertical resistance*[3]).

Figure 1
Flow chart for the design of masonry walls to resist lateral actions



The design procedure is iterative and may be summarised as follows:

1. Make initial assumption of support condition.
2. Make assumptions as to strength and thickness of masonry unit required; the minimum wall thickness or thickness of one leaf of a cavity wall is 100mm.
3. Check serviceability slenderness limits. For wall panels supported top and bottom only, h should be limited to $30t$. For other support conditions use Figure 2 below or Figures 3 and 4 on page 6.
4. Determine orthogonal ratio, μ, and hence bending moment coefficient appropriate to panel shape (Table 2).
5. Determine the design value of the applied moment, M_{Ed}.
6. Check the design value of the moment of resistance, M_{Rd}.
7. If $M_{Rd} \leq M_{Ed}$ then the wall is acceptable – if not return to either step 1 or 2 and modify.
8. Check shear.

Cavity walls

In a cavity wall, the design lateral load per unit area, W_{Ed}, may be apportioned (either according to capacity or stiffness) between the two leaves, provided that the wall ties are capable of transmitting the actions that result from the apportionment.

Lateral resistance using arching

Where a masonry wall is built between supports capable of resisting an arch thrust, then it may be assumed that a horizontal or vertical arch develops within the thickness of the wall in resisting a lateral load. The analysis can be based upon a three-pin arch, and the bearing of the arch thrust at the supports and at the central hinge should be assumed to be 0.1 times the thickness of the wall.

Figure 2
Limiting height and length to thickness ratios of walls restrained on all four edges

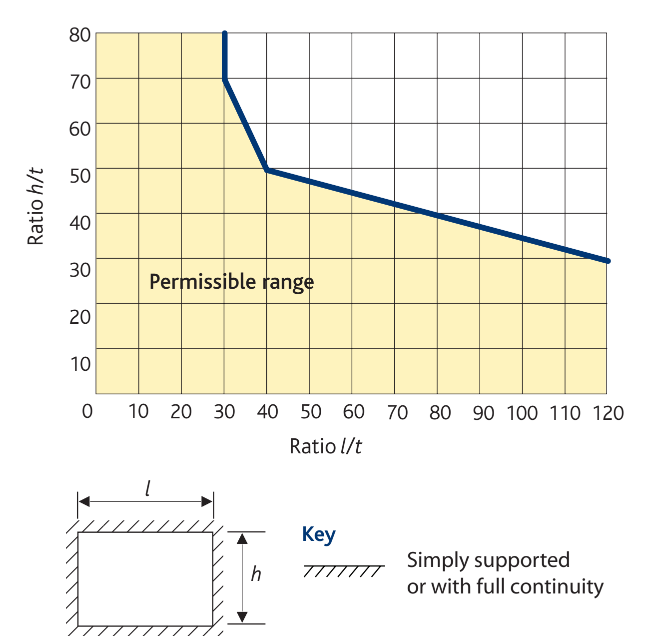
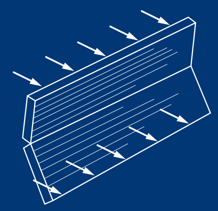
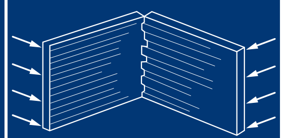


Table 1
Characteristic flexural strength of masonry, f_{xk1} and f_{xk2}, in N/mm²

	Values of f_{xk1} Plane of failure parallel to bed joints			Values of f_{xk2} Plane of failure perpendicular to bed joints		
						
Mortar strength class:						
	M12	M6 & M4	M2	M12	M6 & M4	M 2
Clay masonry units of Groups 1 and 2 having a water absorption[a] of:						
Less than 7%	0.7	0.5	0.4	2.0	1.5	1.2
Between 7% & 12%	0.5	0.4	0.35	1.5	1.1	1.0
Over 12%	0.4	0.3	0.25	1.1	0.9	0.8
Calcium silicate brick-sized[b] masonry units						
	0.3		0.2	0.9		0.6
Aggregate concrete brick-sized[b] masonry units						
	0.3		0.2	0.9		0.6
Aggregate concrete masonry units and manufactured stone of Groups 1 and 2 and AAC[c] masonry units used in walls of thickness up to 100 mm[d,e] of declared compressive strength (N/mm²):						
2.9				0.4		0.4
3.6	0.25		0.2	0.45		0.4
7.3				0.6		0.5
Aggregate concrete masonry units and manufactured stone of Groups 1 and 2 and AAC[c] masonry units used in walls of thickness of 250 mm or greater[d,e], of declared compressive strength (N/mm²):						
2.9				0.25		0.2
3.6	0.15		0.1	0.25		0.2
7.3				0.25		0.3
Aggregate concrete masonry units and manufactured stone of Groups 1 and 2 and AAC[c] masonry units used in walls of any thickness[d], of declared compressive strength (N/mm²):						
10.4	0.25		0.2	0.75		0.6
≥ 17.5				0.9[f]		0.7[f]

Key

a Tests to determine the water absorption of clay masonry units are to be conducted in accordance with BS EN 772–7[7].

b Units not exceeding 337.5 mm × 225 mm × 112.5 mm.

c Autoclaved aerated concrete (aircrete).

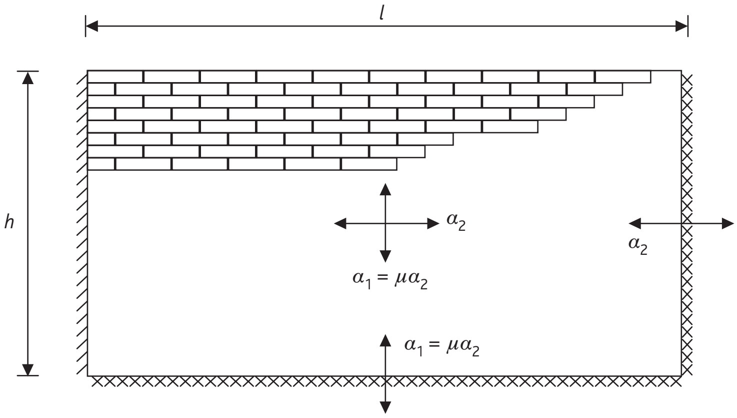
d The thickness should be taken as the thickness of the wall, for a single-leaf wall, or the thickness of the leaf, for a cavity wall.

e Linear interpolation may be used to obtain the values of f_{xk1} and f_{xk2} for:
1) wall thicknesses greater than 100 mm and less than 250 mm;
2) compressive strengths between 2.9 N/mm² and 7.3 N/mm² in a wall of given thickness.

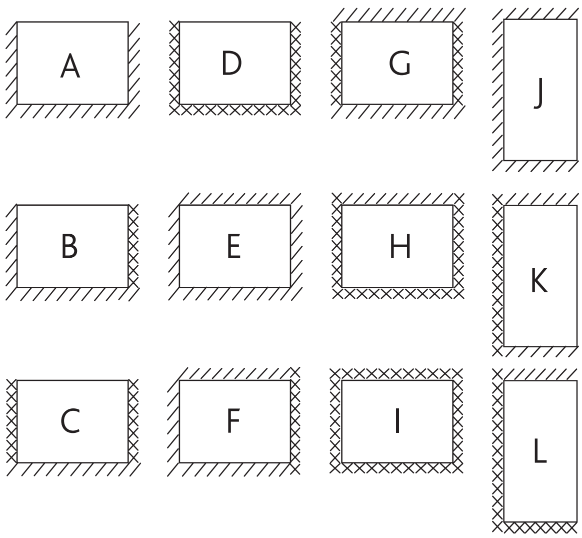
f When used with flexural strength in the parallel direction, assume the orthogonal ratio μ = 0.3.

Table 2

Bending moment coefficient, α_1, in single-leaf laterally loaded wall panels of thickness ≤ 250 mm



Wall support conditions



Key

——— Free edge

/////// Simply supported edge

XXXXXX Fully restrained continuous edge

Notes

1. μ is the orthogonal ratio (f_{xk1}/f_{xk2}).
2. Linear interpolation may be used.
3. Walls having an h/l ratio of less than 0.3 will tend to span vertically.
4. Walls having an h/l ratio of more than 2.0 will tend to span horizontally.
5. Data based on tables presented in *Concrete masonry designers handbook*[4].

Wall support condition A

μ	h/l 0.30	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1.00	0.031	0.045	0.059	0.071	0.079	0.085	0.090	0.094
0.90	0.032	0.047	0.061	0.073	0.081	0.087	0.092	0.095
0.80	0.034	0.049	0.064	0.075	0.083	0.089	0.093	0.097
0.70	0.035	0.051	0.066	0.077	0.085	0.091	0.095	0.098
0.60	0.038	0.053	0.069	0.080	0.088	0.093	0.097	0.100
0.50	0.040	0.056	0.073	0.083	0.090	0.095	0.099	0.102
0.40	0.043	0.061	0.077	0.087	0.093	0.098	0.101	0.104
0.35	0.045	0.064	0.080	0.089	0.095	0.100	0.103	0.105
0.30	0.048	0.067	0.082	0.091	0.097	0.101	0.104	0.107
0.25	0.050	0.071	0.085	0.094	0.099	0.103	0.106	0.109
0.20	0.054	0.075	0.089	0.097	0.102	0.105	0.108	0.111
0.15	0.060	0.080	0.093	0.100	0.104	0.108	0.110	0.113
0.10	0.069	0.087	0.098	0.104	0.108	0.111	0.113	0.115
0.05	0.082	0.097	0.105	0.110	0.113	0.115	0.116	0.117

Wall support condition B

μ	h/l 0.30	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1.00	0.024	0.035	0.046	0.053	0.059	0.062	0.065	0.068
0.90	0.025	0.036	0.047	0.055	0.060	0.063	0.066	0.068
0.80	0.027	0.037	0.049	0.056	0.061	0.065	0.067	0.069
0.70	0.028	0.039	0.051	0.058	0.062	0.066	0.068	0.070
0.60	0.030	0.042	0.053	0.059	0.064	0.067	0.069	0.071
0.50	0.031	0.044	0.055	0.061	0.066	0.069	0.071	0.072
0.40	0.034	0.047	0.057	0.063	0.067	0.070	0.072	0.074
0.35	0.035	0.049	0.059	0.065	0.068	0.071	0.073	0.074
0.30	0.037	0.051	0.061	0.066	0.070	0.072	0.074	0.075
0.25	0.039	0.053	0.062	0.068	0.071	0.073	0.075	0.077
0.20	0.043	0.056	0.065	0.069	0.072	0.074	0.076	0.078
0.15	0.047	0.059	0.067	0.071	0.074	0.076	0.077	0.079
0.10	0.052	0.063	0.070	0.074	0.076	0.078	0.079	0.080
0.05	0.060	0.069	0.074	0.077	0.079	0.080	0.081	0.082

Wall support condition C

μ	h/l 0.30	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1.00	0.020	0.028	0.037	0.042	0.045	0.048	0.050	0.051
0.90	0.021	0.029	0.038	0.043	0.046	0.048	0.050	0.052
0.80	0.022	0.031	0.039	0.043	0.047	0.049	0.051	0.052
0.70	0.023	0.032	0.040	0.044	0.048	0.050	0.051	0.053
0.60	0.024	0.034	0.041	0.046	0.049	0.051	0.052	0.053
0.50	0.025	0.035	0.043	0.047	0.050	0.052	0.053	0.054
0.40	0.027	0.038	0.044	0.048	0.051	0.053	0.054	0.055
0.35	0.029	0.039	0.045	0.049	0.052	0.053	0.054	0.055
0.30	0.030	0.040	0.046	0.050	0.052	0.054	0.055	0.056
0.25	0.032	0.042	0.048	0.051	0.053	0.054	0.056	0.057
0.20	0.034	0.043	0.049	0.052	0.054	0.055	0.056	0.058
0.15	0.037	0.046	0.051	0.053	0.055	0.056	0.057	0.059
0.10	0.041	0.048	0.053	0.055	0.056	0.057	0.058	0.059
0.05	0.046	0.052	0.055	0.057	0.058	0.059	0.059	0.060

Wall support condition D

μ	h/l 0.30	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1.00	0.013	0.021	0.029	0.035	0.040	0.043	0.045	0.047
0.90	0.014	0.022	0.031	0.036	0.040	0.043	0.046	0.048
0.80	0.015	0.023	0.032	0.038	0.041	0.044	0.047	0.048
0.70	0.016	0.025	0.033	0.039	0.043	0.045	0.047	0.049
0.60	0.017	0.026	0.035	0.040	0.044	0.046	0.048	0.050
0.50	0.018	0.028	0.037	0.042	0.045	0.048	0.050	0.051
0.40	0.020	0.031	0.039	0.043	0.047	0.049	0.051	0.052
0.35	0.022	0.032	0.040	0.044	0.048	0.050	0.051	0.053
0.30	0.023	0.034	0.041	0.046	0.049	0.051	0.052	0.053
0.25	0.025	0.035	0.043	0.047	0.050	0.052	0.053	0.054
0.20	0.027	0.038	0.044	0.048	0.051	0.053	0.054	0.055
0.15	0.030	0.040	0.046	0.050	0.052	0.054	0.055	0.056
0.10	0.034	0.043	0.049	0.052	0.054	0.055	0.056	0.057
0.05	0.041	0.048	0.053	0.055	0.056	0.057	0.058	0.059

Wall support condition E

μ	h/l 0.30	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1.00	0.008	0.018	0.030	0.042	0.051	0.059	0.066	0.071
0.90	0.009	0.019	0.032	0.044	0.054	0.062	0.068	0.074
0.80	0.010	0.021	0.035	0.046	0.056	0.064	0.071	0.076
0.70	0.011	0.023	0.037	0.049	0.059	0.067	0.073	0.078
0.60	0.012	0.025	0.040	0.053	0.062	0.070	0.076	0.081
0.50	0.014	0.028	0.044	0.057	0.066	0.074	0.080	0.085
0.40	0.017	0.032	0.049	0.062	0.071	0.078	0.084	0.088
0.35	0.018	0.035	0.052	0.064	0.074	0.081	0.086	0.090
0.30	0.020	0.038	0.055	0.068	0.077	0.083	0.089	0.093
0.25	0.023	0.042	0.059	0.071	0.080	0.087	0.091	0.096
0.20	0.026	0.046	0.064	0.076	0.084	0.090	0.095	0.099
0.15	0.032	0.053	0.070	0.081	0.089	0.094	0.098	0.103
0.10	0.039	0.062	0.078	0.088	0.095	0.100	0.103	0.106
0.05	0.054	0.076	0.090	0.098	0.103	0.107	0.109	0.110

Wall support condition F

μ	h/l 0.30	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1.00	0.008	0.016	0.026	0.034	0.041	0.046	0.051	0.054
0.90	0.008	0.017	0.027	0.036	0.042	0.048	0.052	0.055
0.80	0.009	0.018	0.029	0.037	0.044	0.049	0.054	0.057
0.70	0.010	0.020	0.031	0.039	0.046	0.051	0.055	0.058
0.60	0.011	0.022	0.033	0.042	0.048	0.053	0.057	0.060
0.50	0.013	0.024	0.036	0.044	0.051	0.056	0.059	0.062
0.40	0.015	0.027	0.039	0.048	0.054	0.058	0.062	0.064
0.35	0.016	0.029	0.041	0.050	0.055	0.060	0.063	0.066
0.30	0.018	0.031	0.044	0.052	0.057	0.062	0.065	0.067
0.25	0.020	0.034	0.046	0.054	0.060	0.063	0.066	0.069
0.20	0.023	0.037	0.049	0.057	0.062	0.066	0.068	0.070
0.15	0.027	0.042	0.053	0.060	0.065	0.068	0.070	0.072
0.10	0.032	0.048	0.058	0.064	0.068	0.071	0.073	0.074
0.05	0.043	0.057	0.066	0.070	0.073	0.075	0.077	0.078

Wall support condition G

μ	h/l 0.30	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1.00	0.007	0.014	0.022	0.028	0.033	0.037	0.040	0.042
0.90	0.008	0.015	0.023	0.029	0.034	0.038	0.041	0.043
0.80	0.008	0.016	0.024	0.031	0.035	0.039	0.042	0.044
0.70	0.009	0.017	0.026	0.032	0.037	0.040	0.043	0.045
0.60	0.010	0.019	0.028	0.034	0.038	0.042	0.044	0.046
0.50	0.011	0.021	0.030	0.036	0.040	0.043	0.046	0.048
0.40	0.013	0.023	0.032	0.038	0.042	0.045	0.047	0.049
0.35	0.014	0.025	0.033	0.039	0.043	0.046	0.048	0.050
0.30	0.016	0.026	0.035	0.041	0.044	0.047	0.049	0.051
0.25	0.018	0.028	0.037	0.042	0.046	0.048	0.050	0.052
0.20	0.020	0.031	0.039	0.044	0.047	0.050	0.052	0.054
0.15	0.023	0.034	0.042	0.046	0.049	0.051	0.053	0.055
0.10	0.027	0.038	0.045	0.049	0.052	0.053	0.055	0.057
0.05	0.035	0.044	0.050	0.053	0.055	0.056	0.057	0.058

Wall support condition H

μ	h/l 0.30	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1.00	0.005	0.011	0.018	0.024	0.029	0.033	0.036	0.039
0.90	0.006	0.012	0.019	0.025	0.030	0.034	0.037	0.040
0.80	0.006	0.013	0.020	0.027	0.032	0.035	0.038	0.041
0.70	0.007	0.014	0.022	0.028	0.033	0.037	0.040	0.042
0.60	0.008	0.015	0.024	0.030	0.035	0.038	0.041	0.043
0.50	0.009	0.017	0.025	0.032	0.036	0.040	0.043	0.045
0.40	0.010	0.019	0.028	0.034	0.039	0.042	0.045	0.047
0.35	0.011	0.021	0.029	0.036	0.040	0.043	0.046	0.047
0.30	0.013	0.022	0.031	0.037	0.041	0.044	0.047	0.049
0.25	0.014	0.024	0.033	0.039	0.043	0.046	0.048	0.051
0.20	0.016	0.027	0.035	0.041	0.045	0.047	0.049	0.052
0.15	0.019	0.030	0.038	0.043	0.047	0.049	0.051	0.053
0.10	0.023	0.034	0.042	0.047	0.050	0.052	0.053	0.054
0.05	0.031	0.041	0.047	0.051	0.053	0.055	0.056	0.056

Wall support condition I

μ	h/l 0.30	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1.00	0.004	0.009	0.015	0.021	0.026	0.030	0.033	0.036
0.90	0.004	0.010	0.016	0.022	0.027	0.031	0.034	0.037
0.80	0.005	0.010	0.017	0.023	0.028	0.032	0.035	0.038
0.70	0.005	0.011	0.019	0.025	0.030	0.033	0.037	0.039
0.60	0.006	0.013	0.020	0.026	0.031	0.035	0.038	0.041
0.50	0.007	0.014	0.022	0.028	0.033	0.037	0.040	0.042
0.40	0.008	0.016	0.024	0.031	0.035	0.039	0.042	0.044
0.35	0.009	0.017	0.026	0.032	0.037	0.040	0.043	0.045
0.30	0.010	0.019	0.028	0.034	0.038	0.042	0.044	0.046
0.25	0.011	0.021	0.030	0.036	0.040	0.043	0.046	0.048
0.20	0.013	0.023	0.032	0.038	0.042	0.045	0.047	0.050
0.15	0.016	0.026	0.035	0.041	0.044	0.047	0.049	0.051
0.10	0.020	0.031	0.039	0.044	0.047	0.050	0.052	0.054
0.05	0.027	0.038	0.045	0.049	0.052	0.053	0.055	0.056

Wall support condition J

μ	h/l 0.30	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1.00	0.009	0.023	0.046	0.071	0.096	0.122	0.151	0.180
0.90	0.010	0.026	0.050	0.076	0.103	0.131	0.162	0.193
0.80	0.012	0.028	0.054	0.083	0.111	0.142	0.175	0.208
0.70	0.013	0.032	0.060	0.091	0.121	0.156	0.191	0.227
0.60	0.015	0.036	0.067	0.100	0.135	0.173	0.211	0.250
0.50	0.018	0.042	0.077	0.113	0.153	0.195	0.237	0.280
0.40	0.021	0.050	0.090	0.131	0.177	0.225	0.272	0.321
0.35	0.024	0.055	0.098	0.144	0.194	0.244	0.296	0.347
0.30	0.027	0.062	0.108	0.160	0.214	0.269	0.325	0.381
0.25	0.032	0.071	0.122	0.180	0.240	0.300	0.362	0.428
0.20	0.038	0.083	0.142	0.208	0.276	0.344	0.413	0.488
0.15	0.048	0.100	0.173	0.250	0.329	0.408	0.488	0.570
0.10	0.065	0.131	0.224	0.321	0.418	0.515	0.613	0.698
0.05	0.106	0.208	0.344	0.482	0.620	0.759	0.898	0.959

Wall support condition K

μ	h/l 0.30	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1.00	0.009	0.021	0.038	0.056	0.074	0.091	0.108	0.123
0.90	0.010	0.023	0.041	0.060	0.079	0.097	0.113	0.129
0.80	0.011	0.025	0.045	0.065	0.084	0.103	0.120	0.136
0.70	0.012	0.028	0.049	0.070	0.091	0.110	0.128	0.145
0.60	0.014	0.031	0.054	0.077	0.099	0.119	0.138	0.155
0.50	0.016	0.035	0.061	0.085	0.109	0.130	0.149	0.167
0.40	0.019	0.041	0.069	0.097	0.121	0.144	0.164	0.182
0.35	0.021	0.045	0.075	0.104	0.129	0.152	0.173	0.191
0.30	0.024	0.050	0.082	0.112	0.139	0.162	0.183	0.202
0.25	0.028	0.056	0.091	0.123	0.150	0.174	0.196	0.217
0.20	0.033	0.064	0.103	0.136	0.165	0.190	0.211	0.234
0.15	0.040	0.077	0.119	0.155	0.184	0.210	0.231	0.253
0.10	0.053	0.096	0.144	0.182	0.213	0.238	0.260	0.279
0.05	0.080	0.136	0.190	0.230	0.260	0.286	0.306	0.317

Wall support condition L

μ	h/l 0.30	0.50	0.75	1.00	1.25	1.50	1.75	2.00
1.00	0.006	0.015	0.029	0.044	0.059	0.073	0.088	0.102
0.90	0.007	0.017	0.032	0.047	0.063	0.078	0.093	0.107
0.80	0.008	0.018	0.034	0.051	0.067	0.084	0.099	0.114
0.70	0.009	0.021	0.038	0.056	0.073	0.090	0.106	0.122
0.60	0.010	0.023	0.042	0.061	0.080	0.098	0.115	0.131
0.50	0.012	0.027	0.048	0.068	0.089	0.108	0.126	0.142
0.40	0.014	0.032	0.055	0.078	0.100	0.121	0.139	0.157
0.35	0.016	0.035	0.060	0.084	0.108	0.129	0.148	0.165
0.30	0.018	0.039	0.066	0.092	0.116	0.138	0.158	0.176
0.25	0.021	0.044	0.073	0.101	0.127	0.150	0.170	0.190
0.20	0.025	0.052	0.084	0.114	0.141	0.165	0.185	0.206
0.15	0.031	0.061	0.098	0.131	0.159	0.184	0.205	0.226
0.10	0.041	0.078	0.121	0.156	0.186	0.212	0.233	0.252
0.05	0.064	0.114	0.164	0.204	0.235	0.260	0.281	0.292

The arch rise, r, is given by:

$r = 0.9t - d_a$

where

t = thickness of the wall

d_a = deflection of the arch under design load

If the length to thickness ratio is 25 or less, d_a may be taken as zero.

The maximum design arch thrust per unit length of wall, N_{ad}, may be determined from:

$$N_{ad} = 1.5 f_d \frac{t}{10}$$

Figure 3

Limiting height and length to thickness ratios of walls restrained at the bottom, the top and one vertical edge

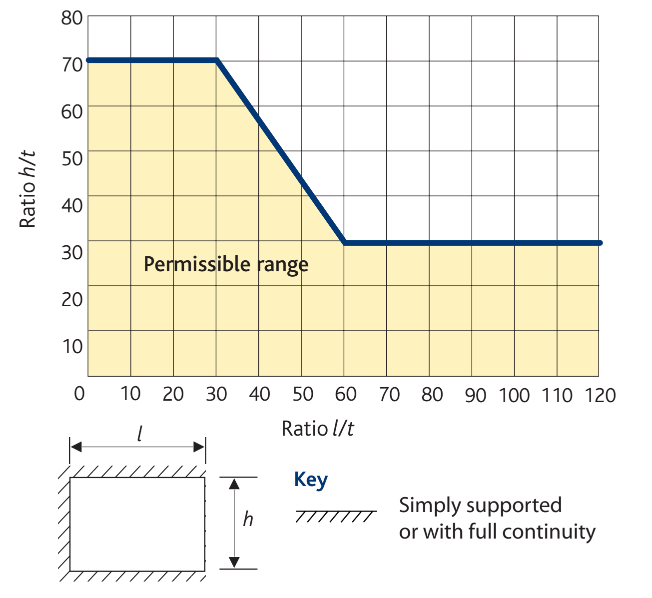
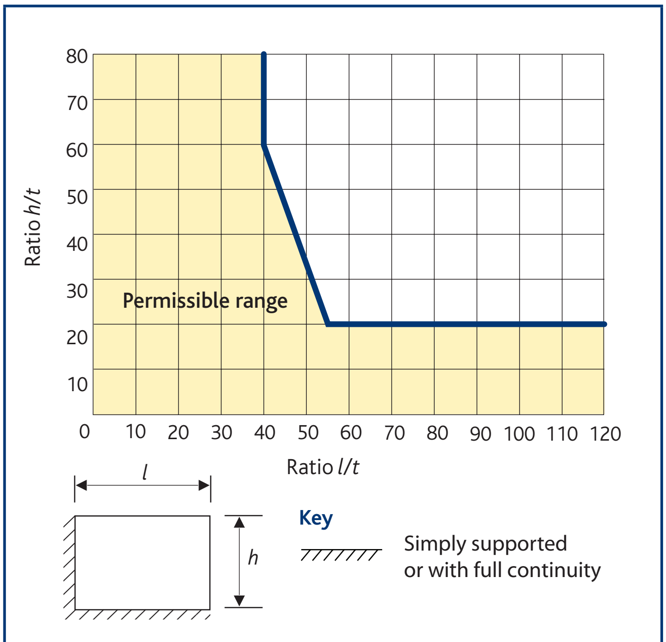


Figure 4

Limiting height and length to thickness ratios of walls restrained at one vertical edge and at the bottom edge, but not the top edge



Where the deflection is small the lateral strength, $q_{lat,d}$, is given by the following:

$$q_{lat,d} = f_d \left(\frac{t}{l_a}\right)^2$$

where

t = thickness of the wall

f_d = design compressive strength of the masonry in the direction of the arch thrust (BS EN 1996–1–1 Cl. 3.6.1)

l_a = length or height of wall between supports capable of resisting the arch thrust

Note the following:

- The slenderness ratio should not exceed 20.
- The design value of vertical stress should not be less than 0.1 N/mm^2.
- Any dpc must be capable of transmitting the horizontal forces.

Shear strength of masonry

The characteristic shear strength of masonry is a function of the characteristic initial shear strength of the masonry and the design compressive stress orthogonal to the shear plane being considered. The values of the initial shear strength of masonry are given in table NA.6 and shown in Table 3.

The characteristic shear strength is given by the following relationships:

- For fully filled mortar joints: $f_{vk} = f_{vko} + 0.4\ \sigma_d \leq 0.065 f_b$
- For unfilled perpend joints, units abutting:

$$f_{vk} = 0.5 f_{vko} + 0.4\ \sigma_d \leq 0.045 f_b$$

where

f_{vk} = characteristic shear strength of masonry

f_{vko} = characteristic initial shear strength of masonry, under zero compressive stress

σ_d = design compressive stress perpendicular to the shear in the member at the level under consideration, using the appropriate load combination based on the average

Table 3

Values of the initial shear strength of masonry, f_{vko}

Masonry units	Strength class of general purpose mortar	Initial shear strength f_{vko} (N /mm^2)		
		General purpose mortar	Thin layer mortar (bed joint ≤ 0.5 mm and ≥ 3 mm)	Light-weight mortar
Clay	M12	0.30	0.30	0.15
	M4 & M6	0.20		
	M2	0.10		
Calcium silicate	M12	0.20	0.40	0.15
	M4 & M6	0.15		
	M2	0.10		
Aggregate concrete, autoclaved aerated concrete, manufactured stone and dimensioned natural stone	M12	0.20	0.30	0.15
	M4 & M6	0.15		
	M2	0.10		

vertical stress over the compressed part of the wall that is providing shear resistance

f_b = normalized compressive strength of the masonry units (as described in Cl.3.1.2.1 of BS EN 1996–1–1) for the direction of application of the load on the test specimens being perpendicular to the bed face

For shell bedded masonry in which two or more equal strips of general purpose mortar are used, each at least 30 m wide, the following relationship may be used:

$$f_{vk} = \frac{g}{t} f_{vko} + 0.4\sigma_d$$

but not greater than the value above for unfilled perpends.

where

g = total of the widths of the mortar strips

t = the thickness of the wall

The applied shear force, V_{Ed}, should be less than the shear resistance of the wall, V_{Rd}, where

$$V_{Rd} = f_{vd}\, t\, l_c$$

where

f_{vd} = design value of the shear strength (f_{vk}/γ_M)

t = thickness of the wall

l_c = length of wall under compression

Table 4

Value of $t_{ch,v}$, the maximum depth of a vertical chase or recess allowed without calculation

Thickness of single-leaf wall or loaded leaf of a cavity wall (mm)	Chases and recesses formed after construction of masonry		Chases and recesses formed during construction of masonry	
	$t_{ch,v}$ (mm)	Maximum width (mm)	Min. wall thickness after chase formed (mm)	Maximum width (mm)
75 – 89	30	75	60	300
90 – 115	30	100	70	300
116 – 175	30	125	90	300
176 – 225	30	150	140	300
226 – 300	30	175	175	300
> 300	30	200	215	300

Notes

1 The maximum depth of the recess or chase should include the depth of any hole reached when forming the recess or chase.

2 Vertical chases which do not extend more than one third of the storey height above floor level may have a depth up to 80 mm and a width up to 120 mm, if the thickness of the wall is 225 mm or more.

3 The horizontal distance between adjacent chases or between a chase and a recess or an opening should not be less than 225 mm.

4 The horizontal distance between any two adjacent recesses, whether they occur on the same side or on opposite sides of the wall, or between a recess and an opening, should not be less than twice the width of the wider of the two recesses.

5 The cumulative width of vertical chases and recesses should not exceed 0.13 times the length of the wall.

6 The minimum thickness of load bearing masonry is 90 mm.

Effect of chases

Eurocode 6 requires that chases and recesses should not impair the stability of all walls, whether designed for vertical or lateral actions, and provides guidance on the value of the depth of a vertical chase, $t_{ch,v}$, at which the reduction in performance (vertical, shear and flexural) may be neglected. Similarly, limits for horizontal and inclined chases, $t_{ch,h}$, are also provided, but there is an overriding requirement that such chases should be positioned above or below a floor within ⅛ of the clear height of the wall. It is also a requirement for horizontal and inclined chases that the eccentricity in the region of the chase is less than $t/3$, where t is the thickness of the wall.

The values for the maximum depth of vertical chases and recesses allowed without calculation, $t_{ch,v}$, are given in table NA.11 and shown in Table 4.

The values for the maximum depth of a horizontal or inclined chase allowed without calculation, $t_{ch,h}$, are given in table NA.12 and shown in Table 5.

Table 5

Value of $t_{ch,h}$, the maximum depth of a horizontal or inclined chase allowed without calculation

Thickness of single-leaf wall or loaded leaf of a cavity wall (mm)	$t_{ch,h}$	
	Unlimited chase length (mm)	Limited chase length ≤ 1250 (mm)
75 – 115	0	0
116 – 175	0	15
176 – 225	10	20
226 – 300	15	25
> 300	20	30

Notes

1 The maximum depth of the chase should include the depth of any hole reached when forming the chase.

2 The horizontal distance between the end of a chase and an opening should not be less than 500 mm.

3 The horizontal distance between adjacent chases of limited length, whether they occur on the same side or on opposite sides of the wall, should be not less than twice the length of the longest chase.

4 In walls of thickness greater than 175 mm, the permitted depth of the chase may be increased by 10 mm if the chase is machine cut accurately to the required depth. If machine cuts are used, chases up to 10 mm deep may be cut in both sides of walls of thickness not less than 225 mm.

5 The width of chase should not exceed half the residual thickness of the wall.

Selected symbols

Symbol	Definition
d_a	Deflection of an arch under design load
f_b	Normalised mean compressive strength of a masonry unit.
f_d	Design compressive strength of masonry in the direction being considered
f_{vd}	Design shear strength of masonry
f_k	Characteristic compressive strength of masonry
f_{vk}	Characteristic shear strength of masonry
f_{vko}	Characteristic initial shear strength of masonry, under zero compressive stress
f_{xk1}	Characteristic flexural strength of masonry having a plane of failure parallel to the bed joints
f_{xk2}	Characteristic flexural strength of masonry having a plane of failure perpendicular to the bed joints
g	Total of the widths of the mortar strips
h	Clear height of a masonry wall
l	Length of a wall (between other walls, between a wall and an opening, or between openings)
l_a	Length or height of wall between supports capable of resisting the arch thrust

Symbol	Definition
l_c	Length of the compressed part of a wall
M_{Ed}	Design value of moment applied
M_{Rd}	Design value of moment of resistance
N_{ad}	The maximum design arch thrust per unit length of wall
$q_{lat,d}$	Design lateral strength per unit area of wall
r	Arch rise
t	Thickness of the wall
$t_{ch,v}$	Maximum depth of vertical chases or recesses without calculation
$t_{ch,h}$	Maximum depth of a horizontal or inclined chase
W_{Ed}	Design lateral load per unit area
Z	Elastic section modulus of a unit height or length of the wall
$\alpha_{1,2}$	Bending moment coefficients
γ_M	Partial factor for materials, including uncertainties about geometry and modelling
σ_d	Design compressive strength
μ	Orthogonal ratio of the flexural strengths of masonry

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